ION GUN DEPOSITION AND ALIGNMENT FOR LIQUID-CRYSTAL APPLICATIONS

This application is a Continuation-In-Part of and claims priority from U.S. Application Serial No. 09/608,798, filed on June 30, 2000.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to an amorphous film having an aligned atomic structure and an apparatus for making such an amorphous aligned film. More particularly, the present invention relates to an amorphous film having an aligned atomic structure prepared by a method in which an aligned film is deposited and aligned in a single step and to an apparatus for depositing and aligning such as an amorphous film in a single step.

2. DESCRIPTION OF THE PRIOR ART

The alignment of liquid crystal molecules on a surface is one of the critical steps in the manufacturing of a liquid crystal display. The industry-wide method for producing such alignment is through the mechanical rubbing of a polyimide surface. This method requires a physical contact between a roller or brush and the polyimide surface. The rubbing process realigns the surface of the polyimide, which then acts as an alignment template for the orientation of the liquid crystal molecules in the preferred direction.

This approach has several disadvantages. For example, because the rubbing method is a contact technique, debris can be generated during the rubbing process resulting in a low process yield. Moreover, additional

cleaning steps are generally required to remove the debris. Also, as the roller or brush rubs the surface of the display, electrostatic charges can build up which may discharge through the thin film transistors (TFT) resulting in a lowering of the process yield. Additionally, the rubbing process requires a relatively soft layer in order to modify the surface in a desired orientation. Thus, choice of materials that are suitable for use in the rubbing process is limited.

U.S. Patent No. 5,770,826 to Callegari et al., the contents of which are incorporated herein by reference, describes the use of low energy ion beams to align surfaces for liquid crystal applications. In these cases, the alignment was performed on an alignment layer deposited by a distinct and separate process. While a wide variety of surfaces were found to be suitable for alignment by an ion beam technique, the reference does not teach the deposition of the alignment layer and the alignment of the layer in a single step.

One of the main driving forces in the liquid crystal industry is the constant reduction in the cost of production. In both the alignment of a polyimide layer via mechanical rubbing/brushing or the alignment of layers using ion beams as described in the previously incorporated U.S. Patent No. 5,770,826, the alignment layer must be applied prior to the alignment procedure. Consequently, the deposition of an alignment layer and subsequent alignment of the alignment layer in separate process steps introduces additional costs into the manufacturing process.

The applicants have found that deposition and alignment of such a layer can be accomplished in a single step, which significantly reduces the manufacturing cost.

SUMMARY OF THE INVENTION

The present invention includes an apparatus for depositing an amorphous film having an aligned atomic structure on a substrate, including:

at least one ion beam source disposed at a designated incident angle of from about 25 to about 60 degrees capable of producing at least one ion beam having an energy from about 100 to 300 eV for bombarding the substrate with the ion beam to simultaneously (a) deposit the amorphous film onto the substrate, and (b) arrange the atomic structure of the amorphous film in at least one predetermined aligned direction.

The present invention further includes an apparatus for depositing an amorphous film having an aligned atomic structure on a substrate, including:

at least one ion beam source disposed at a designated incident angle of from about 25 to about 60 degrees capable of producing at least one ion beam having an energy from about 100 to 300 eV; and

a collimnator placed in the path of the ion beam produced from the ion beam source between the substrate and the ion beam source at a designated incident angle with the ion beam for bombarding the collimnator to sputter material of the collimnator onto the substrate and thereby simultaneously (a) deposit the amorphous film onto the substrate and (b) arrange the atomic structure of the amorphous film in at least one predetermined aligned direction.

The present invention further includes an amorphous film having an aligned atomic structure disposed on a substrate prepared by one of the following methods:

(a) a method including the step of:

bombarding the substrate with at least one ion beam from at least one ion beam source at a designated incident angle, wherein the ion beam has an energy from about 100 to 300 eV and the designated incident angle is from about 25 to about 60 degrees and wherein the amorphous film is a diamond-like carbon film, to simultaneously (a) deposit the amorphous film onto the substrate, and (b) arrange the atomic structure of the amorphous film in at least one predetermined aligned direction; or

(b) a method including the step of:

bombarding a collimnator placed in the path of an ion beam from an ion beam source between the substrate and the ion beam source at a designated incident angle, wherein the ion beam has an energy from about 100 to 300 eV and the designated incident angle is from about 25 to about 60 degrees and wherein the amorphous film is a diamond-like carbon film, to sputter material of the collimnator onto the substrate and to simultaneously (a) deposit the amorphous film onto the substrate and (b) arrange the atomic structure of the amorphous film in at least one predetermined aligned direction.

The method by which these films are prepared is a dry deposition and alignment technique, which reduces the need for pre- and post- wet processing. The present method is also a non-contact deposition and alignment technique, which reduces any potential contamination of the surface by extraneous debris, such as those commonly encountered in the contact rubbing techniques of the prior art.

Accordingly, the present invention provides a simple and cost effective method of forming easily processed aligned films on which liquid crystals can be aligned for use in wide viewing angle liquid-crystal displays.

Applicants have found that when fabricated into display cells, the alignment layers according to the present invention have sufficient anchoring energies. In addition, the measured pre-tilt angles of the films are typically about 4 degrees or less, which is well within the range required for fabricated into display cells.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic of an ion beam source.

Fig. 2 depicts the geometry of the ion source relative to the substrate, wherein θ (theta) is the angle of incidence.

Fig. 3 is a schematic of an embodiment with a fixed substrate.

Fig. 4 is a schematic of an embodiment with a moving substrate.

Fig. 5 is a schematic of an embodiment in which an aligned film on a moving substrate is obtained using two ion sources.

Fig. 6 is a schematic of an embodiment employing two ion guns in which an aligned film on a moving substrate is obtained by a combination of sputter deposition and direct alignment.

Fig. 7 illustrates an embodiment with a single ion source in which an aligned film on a moving substrate is obtained using a collimnator.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides an apparatus for depositing and aligning an amorphous film in a single step.

The present invention further provides a method of forming an aligned film on a substrate in a single step by combining the deposition and alignment of an alignment layer into a single-step using ion beam processing.

The present invention still further provides an amorphous film having an aligned atomic structure prepared by a method in which an aligned film is deposited and aligned in a single step.

The term "aligned film" refers to a film in which the atomic or molecular structure of the film, or the atomic or molecular surface structure thereof, has a predetermined direction or orientation. According to the present invention, an alignment film is deposited and the atomic or molecular structure of the alignment film is aligned in at least one desired direction through use of an ion beam.

Apparatus

The apparatus for depositing an amorphous film having an aligned atomic structure includes:

at least one ion beam source disposed at a designated incident angle of from about 25 to about 60 degrees capable of producing at least one ion beam having an energy from about 100 to 300 eV for bombarding the substrate with the ion beam to simultaneously (a) deposit the amorphous film onto the substrate, and (b) arrange the atomic structure of the amorphous film in at least one predetermined aligned direction.

The apparatus of the present invention employs an ion beam source, for example, a broad beam ion source, for the deposition of amorphous diamond-like carbon films and, at the same time, films that are deposited by

such a source are given an alignment direction suitable for, for example, the fabrication of liquid crystal displays.

The apparatus for fabricating such a film includes a vacuum chamber within which an ion source would be located. The ion source could be, for example, a broad beam Kaufman-type ion source within which a hydrocarbon gas would be introduced such as methane or acetylene.

Within the ion source, a plasma is generated which is included of carbon ions as well as carbon containing complex ions, for example CH_x^+ where x can assume a variety of values depending upon the precursor gas as well as the operating parameters of the ion source including gas pressure and operating power of the ion source. The extraction of ions from the ion source can be accomplished through the application of an electrical potential between the ion source and the substrate that is to be exposed to the ion beam.

Preferably, the extraction of ions for the purpose of depositing a film and aligning the film in a pre-determine orientation is typically in the range of 100 to 300 eV.

The energy of the impinging species on the surface of the substrate must in all cases be kept below the sputter threshold as above this level, a net removal of material will occur at the substrate resulting in an etching of the surface. It should be noted that some of the ions can be neutralized after they are extracted from the ion source by, for example, charge exchange neutralization, such that the energetic species that arrive at the substrate will be a combination of ions and neutrals.

In order to impart a preferred orientation to the film that is deposited and aligned on the surface of the substrate, the geometry of the system is

set such that the angle of incidence between the ion source and the substrate is typically in the range between 25 and 60 degrees.

The substrate that is to be processed by the described apparatus can be either stationery with respect to the ion source or it can be moved with respect to the ion source. If the dimensions of the ion source are smaller than that of the substrate to be exposed to the ion source, it is preferable that either the ion source or sources or the substrate or substrates be moveable in the range of a substrate where they impinge on the substrate as both ions and neutral species. With the energy of the impinging ions and neutrals chosen in the range of 100 to 300 eV, a net deposition of a carbon containing films will be found on the surface of the substrate.

The apparatus that is to be used for the deposition and alignment of the amorphous film therefore incorporates one or more ion beam sources that can be configured in a number of different embodiments.

In the first, one or more ion sources can be held in a fixed position with the substrate to be exposed to the ion beam source is also held in a stationary position.

In a second embodiment, one or more ion sources can be held in a fixed position while the substrates to be coated with the aligned amorphous film are moved beneath the ion sources. In this embodiment, substrates larger than the ion sources can be processed.

In a third embodiment, the substrate or substrates to the processed are held stationary whereas the ion sources are moved relative to the substrates. Once again in this embodiment, the movement of the ion sources allows for the processing of substrates that are larger than the ion sources.

In a fourth embodiment of the apparatus either the substrates or the ion sources are capable of movement, but the angle of incidence of the ion sources relative to one another can be the same or different. Thus, the angle of incidence of the ion sources relative to one another can be fixed for the duration of the process or it can be variable, i.e., changed during the processing of the substrates.

In a fifth embodiment of the apparatus a collimnator is incorporated in the apparatus. The collimnator is placed between the ion sources and the substrate such that the position of the collimnator allows for the sputtering of the collimnator. In this embodiment, the sputtered material can be collected on the surface of the substrate resulting in the growth of a film on the surface and the growing film can be simultaneously aligned by the energetic bombardment from the ion sources. In this embodiment, the ion beam extracted from the ion source is not limited to hydrocarbon gases and can include such species as argon and /or nitrogen. The designated incident angle is chosen such that it produces a net deposition on a surface of the substrate.

In all embodiments described herein above, the ion beam source is preferably an ion gun and can further include neutral molecules. The ion beam source can include a first ion beam source to produce a first ion beam and a second ion beam source to produce a second ion beam for bombarding simultaneously with the first and the second ion beams.

The apparatus according to the present invention can include means for moving the substrate relative to the ion beam source and/or means for moving the ion beam source relative to the substrate.

The apparatus can further include means for moving at least one ion beam source relative to the others and relative to the substrate.

The apparatus can still further include means for varying the designated incident angle in the first or the second ion beam such that the designated incident angle in the first or the second ion beam is different from the designated incident angle of the other. The designated incident angle is chosen such that it produces a net deposition on a surface of the substrate.

The apparatus can additionally include means for varying the designated incident angle in the first or the second ion beam over time and/or means for moving the substrate or the ion beam source relative to the other over time.

In a preferred embodiment, where the apparatus includes a collimnator in the path of the ion beam between the substrate and the ion beam source at a designated incident angle for sputtering material of the collimnator onto the substrate, the apparatus preferably includes:

at least one ion beam source disposed at a designated incident angle of from about 25 to about 60 degrees capable of producing at least one ion beam having an energy from about 100 to 300 eV; and

a collimnator placed in the path of the ion beam produced from the ion beam source between the substrate and the ion beam source at a designated incident angle with the ion beam for bombarding the collimnator to sputter material of the collimnator onto the substrate and thereby simultaneously (a) deposit the amorphous film onto the substrate and (b) arrange the atomic structure of the amorphous film in at least one predetermined aligned direction.

In this embodiment the apparatus can further include means for moving the substrate or the ion beam source relative to the other and to the collimnator over time.

Method

Referring to Fig. 1, an ion beam source is shown. Through gas inlet 1 a carbon-containing gas, preferably a hydrocarbon gas, such as methane, is introduced into the plasma chamber 2, i.e., discharge chamber of an ion beam source.

The carbon-containing gas optionally can be mixed with an inert gas, such as, argon or nitrogen such that argon and/or nitrogen can be introduced along with the hydrocarbon gas into the discharge chamber. The gas is ionized in the discharge chamber to produce an ion beam 4 including atoms and ions, which are then accelerated out of the ion source through the application of accelerating voltages. Sufficient voltage is applied to the ion beam 4 to accelerate the atoms and ions out of the ion beam source.

An electron source 3 for beam neutralization is disposed, for example, in close proximity along the path of the ion beam 4 to neutralize the ion beam. Neutralization can also be accomplished with a tungsten or tantalum wire strung across the ion beam source. Upon electron neutralization of the beam using electron source 3, the ion beam can further include neutral molecules in addition to ions and atoms.

The energy of the impinging species is kept below a level such that a net accumulation, i.e., net deposition, is recorded on the substrate surface. The energy of the depositing species must be below the energy required to permit deposition of an alignment layer on the substrate. If this

condition is not satisfied, then the result will be a net etch, or at the very least, no net deposition.

In these experiments, carbon energies below 500 eV were used. Preferably, the ion beam has an energy from about 100 to 500 eV. However, higher energies are also possible as long as they satisfy the constraints discussed above.

The deposition rate is a function of the sticking coefficient of the deposited species as well as the number of incident atoms at the substrate surface as a function of time. The deposition rate of the film can be controlled by varying the ion current density, the time of exposure of the surface to the ion beam, or both.

The angle of incidence of the depositing energetic species, i.e., the designated incident angle for bombardment, also controls the alignment properties of the deposited film.

Referring to Fig. 2, the geometry of the ion source relative to the substrate 11 is depicted, wherein θ (theta) is the angle of incidence, which is the designated incident angle for bombardment by ion beam 4. Preferably, the angle of incidence is from about 10 to about 70 degrees. More preferably, the angle of incidence is from about 25 to about 60 degrees.

Deposition and alignment can be accomplished in either a static or dynamic mode of operation. As shown in Fig. 3, substrate 11 can be held fixed relative to the ion source 10 generating the ion beam 4 during the process. Alternatively, as shown in Fig. 4, substrate 11 can be moved relative to the ion source 10 in a direction shown by arrows along the x-axis such that substrate 11 is bombarded by the ion beam during the

process. Both of these embodiments result in the deposition of an alignment layer for liquid crystal display applications.

Fig. 5 shows an embodiment in which an aligned film on a moving substrate is obtained using more than one source, i.e., two ion sources.

In this embodiment, two ion guns are used to produce an alignment layer. The first ion source, i.e., a deposition ion gun 20, preferably has a perpendicular or close to perpendicular orientation with respect to the substrate 11. The second ion source, i.e., an alignment ion gun 21, is oriented such that the ion beam forms an angle θ (theta) with the substrate, as shown in Figure 5.

Preferably, the designated incident angle in the first ion beam is different from designated incident angle of the second ion beam. Typically, the angle between the substrate and the second ion source is from about 25 to about 60 degrees. An angle of about 35 degrees is advantageously used to align the films.

In general, substrate 11 is moved relative to the ion sources 20 and 21 in a direction shown by arrows along the x-axis such that substrate 11 is bombarded by the ion beam during the process. However, depending on the movement of the substrate or the ion beam source, the designated incident angle used to both deposit and to align can vary over time.

Other typical but non-limiting parameters are listed below:

DEPOSITION GUN:

Gas Flow:	CH_4:	6 sccm
	Ar:	3 sccm

Operating Pressure:	$5x10^{-2}$ Pa
Beam Energy:	300 eV
Beam Current:	50 mA

ALIGNMENT GUN:

Gas Flows:	Ar: 14 sccm
Operating Pressure:	$5x10^{-2}$ Pa
Beam Energy:	200 eV
Beam Current:	100 mA

Fig. 6 shows an embodiment employing two ion guns in which an aligned film on a moving substrate is obtained by a combination of sputter deposition and direct alignment.

Sputter ion gun 30 is directed at a sputter material target 32, which is then bombarded with atoms and ions from the sputter ion gun resulting in a transfer of material from the target to the substrate.

The target can be, but is not limited to, carbon. It is highly desirable that the film is optically transparent in the visible spectrum. Accordingly, a diamond-like carbon film is preferred.

Preferably, the angle between the target and the substrate is from 30 to 60 degrees. The operating parameters of the alignment gun are similar to those described above. The alignment gun 31 provides desired alignment and imparts desired texture to the film. Substrate 11 can be moved relative to the sputter material target 32 and ion source 31 in a direction shown by arrows along the x-axis such that substrate 11 is bombarded by the sputter beam and the ion beam during the process.

Fig. 7 illustrates an embodiment with a single ion source 40 in which an aligned film on substrate 11 is obtained using collimnator 41, i.e., a "bee's nest collimnator, preferably constructed of carbon. As above, substrate 11 moves relative to the ion beam source over time in a direction shown by arrows along the x-axis during the deposition and alignment.

In this embodiment, collimnator 41 is placed in the path of the incident ion beam, which includes ions and atoms. A portion of the incident energetic species will sputter the collimnator in a forward direction, which will result in a net deposition of a film on a surface of substrate 11 and, simultaneously, the ion beam including ions and atoms that passes through the collimnator will align the deposited layer in the same step.

Film

The present invention provides a simple and cost effective method of forming easily processed aligned films. The amorphous film of the present invention is optically transparent in the visible spectrum.

Preferably, the amorphous film is prepared by the method of the present invention. The method includes the step of: bombarding the substrate with at least one ion beam from at least one ion beam source at a designated incident angle to simultaneously (a) deposit the amorphous film onto the substrate and (b) arrange the atomic structure of the amorphous film in at least one predetermined aligned direction.

Preferably, the ion beam has an energy from about 100 to 300 eV, more preferably, from about 200 to 300 eV, and the designated incident angle is from about 25 to about 60 degrees. Preferably, the amorphous film is a diamond-like carbon film.

The ion beam includes impinging species the energy of which is kept below the energy required for etching the amorphous film on a surface of the substrate. The designated incident angle is selected such that it produces a net deposition on a surface of the substrate.

The ion beam is generated using an ion gun and can further include neutral molecules.

The bombarding can be carried out simultaneously using, for example, a first ion beam and a second ion beam, such that the designated incident angle in the first ion beam can be the same or different from the designated incident angle of the second ion beam. Further, the designated incident angles can be adapted to vary over time. Thus, the method can further include moving the substrate or the ion beam source relative to the other over time.

The method can further include the placing a collimnator in the path of the ion beam between the substrate and the ion beam source at a designated incident angle to sputter material of the collimnator onto the substrate. Thus, the film can be prepared by bombarding a collimnator placed in the path of an ion beam from an ion beam source between the substrate and the ion beam source at a designated incident angle to sputter material of the collimnator onto the substrate and to simultaneously (a) deposit the amorphous film onto the substrate and (b) arrange the atomic structure of the amorphous film in at least one predetermined aligned direction.

A liquid cell fabricated using a film deposited and aligned with an ion source by the method of the present invention as the alignment layer

displayed excellent contrast. The following parameters were used for the deposition and alignment:

Gas Flows:	CH_4: 10 sccm
	Ar: 1.5 sccm
Operating Pressure:	5×10^{-2} Pa
Beam Energy:	200 eV
Beam Current:	100 mA

Surprisingly, the measured pre-tilt angle in this case was 4 degrees, which is well within the range required for fabricated into display cells.

In addition, applicants have unexpectedly found that when fabricated into display cells, the alignment layers prepared according to the present invention have sufficient anchoring energies.

Anchoring energy is defined as the energy, which describes how good the liquid crystal directors are aligned to the alignment direction of the alignment layer. The alignment direction in the present case is the projection of the ion beam traveling direction on the alignment layer surface. The higher the anchoring energy, the closer the liquid crystal directors are aligned to the alignment direction.

For most liquid crystal displays, a high anchoring energy is necessary to obtain good optical performance. The rubbed polyimide films used in current liquid crystal displays usually give an anchoring energy of 1.0×10^{-3} N/m or higher, which is considered to be strong anchoring. In contrast, non-contact alignment methods usually give an anchoring energy less than that of rubbed polyimide. The alignment layers prepared according to the present invention unexpectedly produce an anchoring energy of 1.0×10^{-3} N/m or higher. This demonstrates that alignment

layers provided by the method of present invention are at least as good as rubbed polyimide.

Thus, the present invention provides a simple and cost effective method of forming easily processed aligned films on which liquid crystals can be aligned to form flat panels suitable for use as wide viewing angle liquid-crystal displays.

Although discussed in the context using the output of ion beam source, in some embodiments a direct writing technique can be used to direct the ion beam to desired regions to form a film having an aligned atomic structure.

The present invention has been described with particular reference to the preferred embodiments. It should be understood that variations and modifications thereof can be devised by those skilled in the art without departing from the spirit and scope of the present invention. Accordingly, the present invention embraces all such alternatives, modifications and variations that fall within the scope of the appended claims.